PROFR. ALLEN THOMSON, ON ADJUSTMENT OF THE EYE.

Fig. 1.

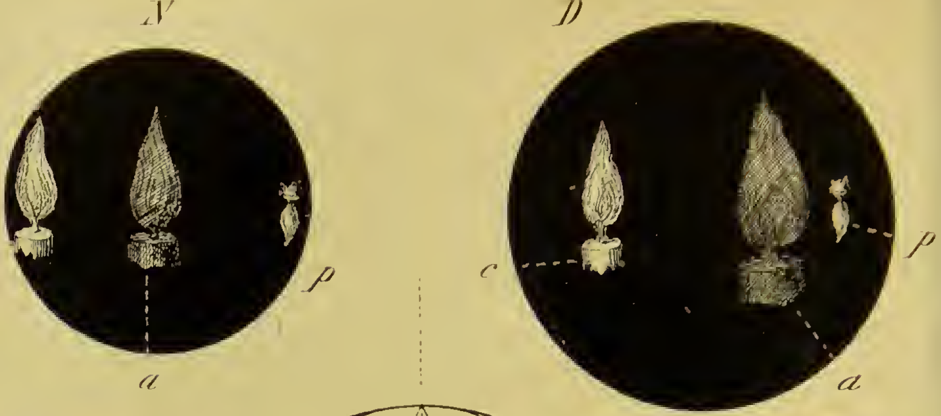


Fig. 2.

Fig. 3.

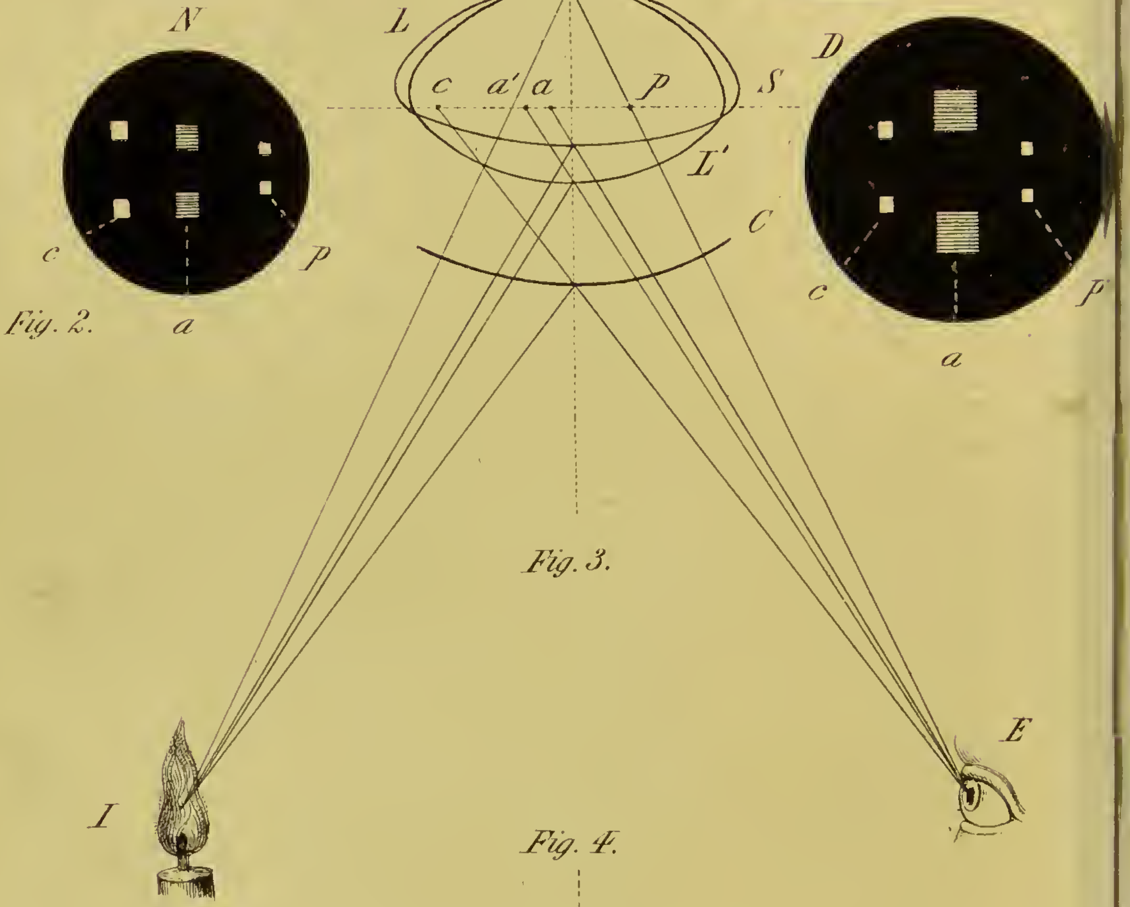
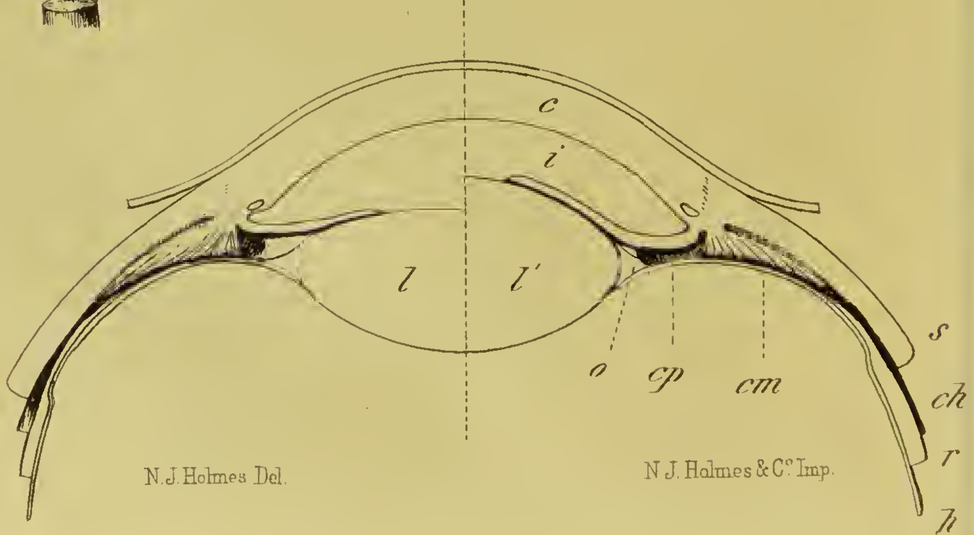


Fig. 4.



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ON THE PHENOMENA AND MECHANISM OF THE FOCAL ADJUSTMENT OF THE EYE TO DISTINCT VISION AT DIFFERENT DISTANCES.

By Professor ALLEN THOMSON, M.D., F.R.SS. L. & E.

The explanation of the mechanism by which the eye may undergo a change of its focal adjustment, or be accommodated to the distinct vision of objects at different distances, has occasioned much difficulty and discussion among optical physiologists. Recent researches appear to have thrown considerable light upon this subject; and as I have been led to repeat and extend some of the experiments which bear upon it, I venture to lay before the reader some account of the present state of this interesting question.

It appears strange that some should have doubted the existence of any power of focal adjustment in the eye, and should have denied the necessity of the occurrence of such a change. The error of this opinion, and the fact that an internal change in the refracting media is required in order to render distinct the vision of objects situated at different distances from the eye, may be satisfactorily proved by several very simple experiments.

1. If, for example, closing one eye, we fix the other alternately on a near and a distant object placed in the same line of vision, it will be found that, when the distant object is viewed, the image of the near one is confused, and when, by an effort, we bring the eye to see the near one distinctly, we have no distinct perception, but only a general vision of the more distant object.

2. If, as in Scheiner's experiment (*Oculus sive fundamentum Opticum, &c.*, 1619), we view with one eye the head of a pin, or some small distinct body, through two minute holes in a card, placed at a less distance from each other than the width of the pupil, we shall find that there is a certain distance—which is that to which the eye is most easily adjusted—at which the pin head appears single, while within and without that place it appears more and more evidently double. Now, the place at which the image appears single is not altogether fixed, but varies within a certain range, according to the adjusting power of the eye. The reason of this is obvious from a consideration of the nature of the experiment. The two small holes admit to the eye two separate pencils of light at a certain amount of divergence, and at a certain distance these may be brought to fall on the same part of the retina, so as to form

a single image by the refractive power of the eye; but when within or without that distance, they cannot be so made to coincide on the retina, and therefore give a double image, either by their point of coincidence falling short of the retina in the one case, or by their reaching beyond it in the other. The power of adaptation is no doubt greatly limited by the fixed position of the two holes in the card, through which the rays of light pass to the eye; but, nevertheless, we find that the eye, when perfect, has the faculty of varying, to some extent, the place at which the image appears single. In those, therefore, who have lost the power of adjustment, the distance at which the pin head appears single will be found invariable.

3. The optometer of Dr. Young, founded on Porterfield's suggestion, and other instruments improved upon it, furnish a convenient method of measuring the extent of this adjusting power; and I have generally made use of it for this purpose in my experiments. A single line, to which a scale of lengths is adapted, is viewed endways with one eye, through a double slit in a small screen, and this line appears double at all places excepting at that for which the eye is adjusted, and there the double lines appear to cross each other. Now, it will be found that, in those who have lost the power of adjustment, there is one invariable point at which the line appears single, or at which the two lines appear to intersect each other, and there is no power by an effort to change its position; but in those, such as the young, with well-constituted eyes, who retain the power of adjustment, it is easy to cause the place of intersection of the two lines to vary to the extent of several inches.

A farther proof of the actual occurrence of a change during adjustment of the eye to different focal distances, has very recently been obtained by Helmholtz and others, through the means of the ocular mirror, or ophthalmoscope—an instrument by which light may be thrown into the eye of a person, so as to enable the observer to examine the image of an external luminous body formed by refraction on the retina. By this means, not only the blood-vessels of the retina and other anatomical peculiarities may be perceived, but it has also been ascertained that the distinctness of the image of the luminous object on the retina varies with the distance at which it is placed, and according as the eye is adjusted for near or distant vision.

The experience of every one, indeed, who has carefully studied the action of the eye, must be considered as quite satisfactory on this point, and a very slight consideration of the subject will show how very limited our distinct perception of objects would have been, had we been deprived of this power; while daily observation of those in whom, from age or earlier defect, this power has become impaired, gives farther evidence to the same effect.

Had the space allotted to this communication permitted, it might have been interesting to present a sketch of the various views that have been taken by physiologists and opticians of the nature and cause of this change. But as the actual phenomena may now be considered as in a great measure determined, the statement of previous views is to be looked upon rather as interesting from their ingenuity, than as necessary to the comprehension of the subject. I will therefore do no more than state the more important progressive steps in the determination of this question. After what has already been said, it is unnecessary even to notice the opinions of those who have held that no change whatever occurs in adjustment; and the opinions of those who have ascribed the change to an alteration in the curvature or position of the cornea, or to the contraction and dilatation of the pupil of the iris, may be very soon disposed of. The cornea is excluded from all participation in the change of adjustment (in the human eye at least) by the ingenious experiments of Young, which have shown that these changes still take place perfectly, although the cornea be covered in front by water, enclosed in an invariable glass-case, or anterior bounding surface; and the view that any changes in the position of the cornea, such as might be due to a change in the length of the axis of the whole eye, is equally excluded, by the observations of Young, Valentin, Senff, Cramer, Helmholtz, and others, which have shown that the earlier experiments of Ramsden, Home, and others, upon such a supposition, was founded on erroneous data, and that, during the changes of adjustment, neither the form nor the position of the cornea undergo such a change as would explain the focal adjustment of the eye for near and distant vision.

The hypothesis that the different states of adjustment may be owing to the varying size of the pupil—which seemed to derive support from the experiment of shortening the focus of the eye by looking through a small hole in a card—is disproved by a great many observations, which tend to show that the size of the pupil may vary to a considerable extent, while the focus of the eye remains the same; by the observations which I have made, that the partial action of belladonna, though sufficient to abolish or greatly impair the contractility of the iris, does not prevent adjustment; by the instances, afterwards referred to, of persons having the power to keep the iris greatly dilated, and yet to perform changes of adjustment; and, more especially, by the interesting cases recently described by Ruete, of congenital absence of the iris, in which, nevertheless, the power of adjustment remained perfect. (*De Iridiremia Congenita*, 1855.)

To Dr. Thomas Young (*On the Mechanism of the Eye*, *Philos. Transactions*, 1793 *and* 1801) we owe the fullest demonstration that the change of adjustment must be connected with the crystalline lens, rather than with any other part of the eye; and it must be allowed that that philosopher had even arrived at the conclusion which accords the nearest with the result of the most recent experiments, that a change of its curvature is the cause of adjustment; although he appears to have erroneously conceived that change of curvature to occur in the posterior rather than in the anterior surface of the lens.

So long as the actual nature of the change was undetermined, it was quite warrantable, on optical principles, to attribute the adjustment, either to a change of form or of position of the lens, or to a combination of both these changes; and, accordingly, we find the names of the first physiologists and opticians among those adopting either of these views. The names of Kepler, Scheiner, Porterfield, Brewster, J. Müller, Mackenzie, Hueck, Ruete, Wallace, are sufficient to show that the hypothesis of a change of position which they held, was, at all events, consistent with sound reasoning and accurate observation.

The other opinion, now shown to be the more correct one, that alterations of the curvature of the lens are the principal cause of the changes of adjustment, arose, as early as 220 years ago, with Descartes (1657), and has been supported by Pemberton, Cowper, John Hunter, Thomas Young, Purkinje, Forbes, and others. So closely, indeed, did some of these authors conceive the lens to be connected with this process, that they attributed to this body a faculty of self-contraction and expansion, or muscular power—an hypothesis which, as will afterwards be stated, receives no support from experimental investigation with improved modern instruments.

Dr. Young came the nearest to an experimental demonstration of the change of curvature of the lens during adjustment to near vision, when he found that, on looking at a bright luminous spot through the slits of the screen of his optometer, while the bars between the slits appeared straight in distant vision, they assumed a curved form whenever his eye was adjusted for a near object.

The more accurate recent knowledge of the phenomena of adjustment has proceeded from a happy adaptation to its illustration of the interesting catoptric experiment, first described by Purkinje in 1823 (*De Examine Physiologico Organi Visus, &c.*, Breslau, 1823), and afterwards applied by Sanson (*Leçons sur les Maladies des Yeux*, Paris, 1837) in 1837, to the examination of the state of the eyes in disease. This consists in the observation of the several images of a light held near the eye, which are seen reflected from the cornea, and from the anterior and posterior surfaces of the lens. In 1841, Hueck (*Die Bewegung der Krystall-linse*, Leipzig, 1841) described the fact that the iris is advanced towards the cornea during adjustment for near vision; but this advance of the iris he considered to be owing to its protrusion by a change in the position rather than in the form of the lens.

In 1849, the idea occurred to the younger Laugenbeck of investigating the phenomena of adjustment by the observation of the reflected images from the different internal surfaces of the eye (*Klinischen Beitrage*, Gottingen, 1849), and he observed the increased curvature of the anterior surface of lens; but his observation did not meet with the attention it merited.

It remained for Cramer of Groningen, and Helmholtz of Bonn, to improve the method of observation, and, by the more full and accurate performance of the catoptric experiments, to demonstrate that the principal change which occurs in the eye during its adaptation for near vision, consists in an advance and increase of curvature of its anterior surface, while the posterior surface undergoes only a very slight change, either of form or position.

The experiments and views of Cramer was first noticed in the Journal of the Medical Society, and the Lancet of the Netherlands, in 1851, and were afterwards more fully published in his prize essay, presented to the Dutch Academy of Sciences in 1853. (*Het Accommodatie vermogen des Oogen Physiologisch taegelicht.* Haarlem, 1853.) Papers by the Dutch physiologist Donders, confirming and illustrating these views, appeared in various numbers of the Nederlandsch Lancet, and I may notice an especially interesting review of the subject in the number for 1852, which, through the kindness of Dr. Charles Wilson of Edinburgh, I have seen. Helmholtz' researches were undertaken, at first, without the knowledge of Cramer's, and were first noticed in the Monthly Report of the Academy of Berlin for Feb. 1853, and more fully published in his Essay on the Accommodation of the Eye, in Arlt Donders and Graefe's Archiv. für Ophthalmologie (vol. i.), in 1855. A very interesting and complete account of the whole subject is to be found in Helmholtz' article on Physiological Optics, contained in Karsten's Allgemeine Encyclopedie der Physik, Leipzig, 1856, and in Otto Funke's new edition or republication of Rud. Wagner's Lehrbuch der Physiologie, 1856.

Having myself repeated these experiments with some modifications, and investigated the causes of the changes which accompany adjustment, by an examination of the internal anatomy of the structures of the eyeball related to it, I have thought some account of the subject might be acceptable to the readers of this Journal. In proceeding to offer these remarks, I will treat of the subject in two divisions: the first comprehending the phenomena ascertained to accompany changes in the focal adjustment of the eyes; the second, the attempt to account for these changes, by the observation of the structure and functions of the internal parts of the eyeball.

The eyes in a state of rest are naturally adjusted for distant vision, and a certain amount of effort, of which we are conscious, around and within the eye, is necessary to see quite distinctly an object placed so near as from six to ten inches. When both eyes are used equally, an accurate convergence of the two optic axes upon the object seen accompanies this adjustment, while, for distant vision, the optic axes approach more and more near to a position of parallelism.

If we close one eye, we can still adjust the open eye alternately to near and distant vision, but with less facility than when both eyes are employed; and it will be found that while the axis of the open eye is kept steadily in the same line of direction, that of the closed eye changes its direction, to a certain extent, along with the changes of adjustment in the open one; but, as has been shown by Müller, Volkmann, and others, and as I have myself experienced, it is apparent that the change of direction or convergence of the optic axes is not so perfect as when the two eyes are employed; from this circumstance, that on opening the closed eye, a double image of any distant body towards which the open eye has been previously adjusted, will be perceived for a second, or very short space of time, until the act of adjustment with the two eyes be perfected.

2nd. A change in the size of the pupil of the iris invariably accompanies the change of its focal adjustment, the pupil being contracted for near, and dilated for distant vision; and it is important to observe, that this occurs whether one eye or both are employed; but the contraction of the pupil is more complete when the convergence of the optic axes is perfect, as when both eyes are used. We shall afterwards consider how far these contractions and dilatations of the pupil are simply associated actions accompanying motions of the different voluntary muscles which give different directions to the eyeball, or are in part independent actions of the iris connected with adjustment.

3rd. It has been ascertained that the iris changes its position during changes of the size of the pupil, the pupillary margin advancing a small degree, or about $\frac{1}{50}$th of an inch during a powerful contraction, and receding from the cornea during the enlargement of the pupil. These changes in the size of the pupil are known to be dependent on the different contractions of the sphincter or orbicular and of the radiating muscular fibres of the iris. But the changes in the position of the iris are dependent on a change of form of the anterior surface of the lens which accompanies adjustment, and to which reference will immediately be made, the iris being advanced by the increased curvature or bulging, and being made to recede by the diminished curvature or flattening of the anterior surface of the lens. This depends upon a fact, not as yet well known or acknowledged by anatomists, but of the truth of which I have fully satisfied myself by examination, viz., that the iris lies closely applied against the anterior surface of the lens. To this fact, and the proofs that may be given of it, I will advert in a later part of this paper. At the time when the pupillary margin of the iris advances in near adjustment, the external margin recedes to a corresponding extent.

4th. It is ascertained by the catoptric examination of the eye, that the cornea does not perceptibly alter its position or form; that the form of the crystalline lens undergoes a great change, being flat for distant, and deeply curved for near vision; and that this change consists chiefly in the advance and increased curvature of the anterior surface of the lens.

In order to observe this very interesting fact, we may select a person under middle age possessing the perfect power of adjustment, and having placed him in a darkened room in such a position that the head may be held steady, a small artificial light is held to the side and in front of one of his eyes, at a distance of six inches, and we then examine at an equal angle from the other side the images from the several reflecting surfaces. These images may be seen with the naked eye, or with a hand magnifying lens; but the best method is to employ a compound microscope of low power, set horizontally on a stand, so that it can be readily adjusted at a proper level to the eye. I employ Smith & Beck's instrument, with an object lens of two and three inches combined, and the erector or second eye-piece introduced, with the tube drawn out to the distance of three inches, so as to give a magnifying power of twenty diameters. The advantage of this arrangement proceeds not so much from the magnifying effect, as from the steady fixed direction in which the eye is viewed, and the distance at which the observer may be placed from the subject of the experiment.

The person under observation is then made alternately to adjust the eye to a near and to a distant object, conveniently placed in one line; and I have found it best, in order to prevent much shifting of the eye which is undergoing adjustment, to cover the eye which is not under observation.

When this arrangement has been made, if the pupil be of sufficient size, three reflected images are perceived, viz., one erect, distinct, and large, to the side next the light, proceeding from the cornea; another, also erect, of a much duller appearance, in which sometimes we scarcely recognise the form of the flame which gives the light, is situated nearer to the middle of the pupil; and a third much smaller but brighter than the last mentioned, and inverted, is placed towards the opposite margin of the pupil from that at which the corneal image of reflection is seen. Of these last two images, the first is from the anterior, the second from the posterior surface of the lens. In many persons in whom the pupil is of small size, we cannot conveniently see the third or inverted image, or we can only do so when the pupil is dilated, as in distant vision; and it is best, therefore, to select a person for observation in whom the pupil is naturally wide, as in the young, or to cause the partial dilatation of the pupil with atropine or belladonna.

When the relative position of the three images has, by the arrangement of the light, &c., been brought into the position represented in figure 1, D, so that the anterior lens image is nearer the margin than the middle of the pupil, while the eye is adjusted for distant vision, it will be found that, whenever the adjustment is changed for distinct vision of a near object, a marked change occurs in the appearance and position of the middle image, or that from the anterior surface of the lens, while that reflected from the cornea undergoes no change, and the posterior inverted image is only very slightly altered. The anterior lens image now becomes suddenly smaller and more distinct, and shifts its place nearer to the corneal image, or nearer to the centre of the pupil, somewhat in the manner shown in figure 1, N. The posterior lens image is, during adjustment for near vision, not perceptibly altered in appearance, but recedes very slightly to a greater distance from the corneal image.

The position, size, and distances of the images have been accurately measured by the instruments employed by Helmholtz for the purpose, particularly by his ophthalmometer. It is difficult at all times to arrange the experiment in such a manner that the reflections from a single light shall give the result now mentioned; and to avoid the ambiguity which might proceed from this circumstance, Helmholtz introduced an important modification of the experiment in which a double light was employed. The reflected images of these from the anterior surface of the lens were found to approach each other, and to be diminished in size when the eye was adjusted for near vision, and to be more distant from each other and larger in distant vision; and Helmholtz founded on his measurements of these changes, an accurate estimate of the change in the form of the lens giving rise to them. The results of this experiment are shown in figure 2, D and N. I have repeated these experiments, both with the single and double lights, in a number of persons, and though I have not had the means of making the precise measurements in the manner now mentioned, I find the results confirmed in every essential particular.

The accompanying diagram, after one suggested by Donders, will give some idea of the nature of these changes as affecting the position of the images in the two conditions of the eye. Let C be the cornea, L a transverse section of the lens of the right eye of the person observed, I the artificial light, and E the eye of the observer, or the microscope employed; and let S represent a plane of projection to which the images are referred. Suppose the eye to be adjusted for distant vision, it will be seen that the rays of light reflected from the three surfaces will pass to the eye of the observer in such directions as to be referred to the relative positions *c*, *a*, and *p* respectively; but when the eye is adjusted for near vision, the image *a* shifts to *a*′, and it will be seen that this corresponds to a projection forwards, and increased curvature of the anterior surface of the lens, as at L′. I have not thought it necessary to represent the change in the posterior image, it being very small; but I may state that it is such as would be produced by a slightly increased curvature of the posterior surface of the lens.

The following is the result of the calculations made by Helmholtz, from the observation of the change in the size of the anterior image of the lens in two persons. The measurements are stated in millimetres, each of which is a little less than $\frac{1}{25}$th of an inch.

In one person the radius of curvature of the anterior surface of the lens for distant vision was 11·9$^{\text{m.}}$; for near vision, 8·6; and the advance of the pupil during the change was ·36. In the second instance, the same respective measurements were as follow:—8·8, 5·9, and ·44$^{\text{m.}}$ The diminution in the radius of curvature of the posterior surface of the lens amounted to ·5$^{\text{m.}}$, but the position of the surface was probably not altered.

It appears, therefore, that while the middle of the posterior surface of the lens remains, during adjustment from distant to near vision, at the same distance from the retina, the whole lens undergoes a thickening, or its antero-posterior axis is increased, and its anterior surface bulges and approaches the cornea. The transverse equatorial diameter of the lens must therefore be diminished, and the principal focus of the lens must be carried forwards; and it would appear, by the calculations of Helmholtz, that the amount of the change actually observed by him is quite sufficient to account for the whole change that occurs in the eye for adjustment to the vision of near objects, and to that of objects at almost an infinite distance.

By means of the instrument employed by Helmholtz, so small a change in the radius of curvature of the cornea as $\frac{1}{200}$th of a millimetre might have been detected, and yet no such change was perceived; from which we may conclude with him, that the form and position of the cornea, and the length of the axis of the whole eye, remain unaltered during adjustment.

Such then are the actual phenomena that can be detected by observation as accompanying the changes of adjustment; and it is now only for the first time that the nature of these phenomena has received anything approaching to an accurate determination.

I now recapitulate the usual phenomena which accompany adjustment from distant to near vision:—1st, The pupil contracts; the pupillary margin of the iris advances somewhat towards the cornea, and its external margin recedes in a corresponding degree. 2nd, The axis or antero-posterior diameter of the crystalline lens is lengthened, while the transverse or equatorial diameter is diminished. This change consists chiefly in the projection forwards, and increased curvature of the anterior surface of the lens, while the posterior surface remains in the same position, but with its curvature slightly deepened. 3rd, No perceptible change has been observed in the size or form of the whole eyeball, nor in the position or curvature of the cornea, nor in the position of the retina. 4th, The adjustment from near to distant vision is attended with changes the opposite of those before mentioned; the lens becoming flattened anteriorly, widened transversely, and its axis shortened. 5th, While the adjustment for near vision is felt to be an active change, and is attended with a sensation of effort, and, when long continued, of fatigue; that for distant vision appears to our feelings more like a return of the eye to a state of rest, and is not usually attended with effort or fatigue. 6th, The motions of the axes of the eyeballs, though usually accompanying the changes of adjustment, are not essential to their production.

In proceeding now, in the second place, to consider the mechanism by which these changes of adjustment may be produced, it will be necessary for me to state very shortly several circumstances connected with the structure of the parts concerned, which involve some modification of the usually received views of the anatomy of these parts.

1st. The posterior surface of the iris lies, in the greater part of its extent, from the margin of the pupil to near its base, in close contact with the anterior surface of the lens; and the inner part of the iris changes its place constantly with that surface. This is a fact which has been stated by several recent writers, and has been fully established by the observations of Cramer, Helmholtz, and Van Reeken. According to Helmholtz, it may be best proved by observation of the fact, that the reflection of a strong light from the iris and front of the lens is not divided by any interval of shadow at the margin of the pupil, which must have been the case had there been any space between the iris and the lens. It may also be ascertained anatomically by sections of the eye in the frozen state. I have repeatedly made such sections of the human eye, and I have in all instances, both in young and in old persons, found the uvea or pigment surface of the iris closely applied to the anterior surface of the lens; but so soon as the specimens are permitted to thaw, and more especially when they have been placed in a preserving fluid, the shrinking of the vitreous humour allowing the lens to fall backwards, causes its separation more or less from the iris, while at the same time the cornea usually projects forwards to a greater degree than before. The posterior chamber of the aqueous humour, therefore, such as it has been described by Sœmmerring and earlier anatomists, has no existence as a free space containing fluid, excepting perhaps, to a very small extent, at and beyond the outer margin of the lens.*

2nd. The lens is suspended in its place chiefly by the zonule of Zinn, and the elastic fibres situated in that structure. I have ascertained that these strong elastic fibres, constituting the orbiculus capsulociliaris, pass from the ora serrata and ciliary processes to a part of the posterior as well as of the anterior surface of the lens near its margin, and in such a manner that it can scarcely be doubted that their action must be, when stretched, to flatten the lens or to shorten its axis.

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* See also Bowman's Lectures on the Eye, &c., fig. 10, page 52; Kolliker's Microscopic Anatomy; T. Warton Jones' beautiful figure of the horizontal section of the eye in Mackenzie's work on the Diseases of the Eye, 4th edition, 1854; Brücke, Anatom. Beschreiburg des Auges, 1847. With the excellent

3rd. The inner ends of the ciliary processes do not, as often represented, overlap the margin of the lens anteriorly, but are situated to the outside of it, having the spreading fibres of the ciliary muscle attached to their outer or anterior borders; and consequently, when drawn inwards towards the lens, the ciliary processes are applied against its margin, and do not press on its anterior surface. The ciliary muscle is attached at its narrow anterior angle by means of elastic tissue to the membrane of Descemet, inside the canal of Schlemm; and these elastic fibres may permit the muscle, during its contraction, to pass backwards to a short distance from the place of its attachment. The external fibres of the ciliary muscle, which are the longest, are inserted into the choroid membrane towards the ora serrata, while the remainder of the fibres spread along the exterior of the ciliary processes, to which and the intervening non-ciliated part of the choroid they are fixed; and finally, the innermost fibres are attached to the base of the iris. The iris, therefore, and the ciliary muscle thus form almost a continuous structure of a contractile nature round the margin and outer part of the front of the lens.

4th. The contraction of the outer part of the ciliary muscle must draw forward the ora serrata of the choroid, or tend to contract that membrane and the hyaloid as a whole in the posterior part of the cavity of the bulb, so as to give firmness and support to the vitreous humour, and prevent the lens from sinking backwards into it. This action must, at the same time, have the effect of relaxing the elastic fibres of the zonule of Zinn. The contraction of the shorter fibres of the ciliary muscle, spreading over the exterior of the ciliary processes, must withdraw these processes and the zonule from the canal of Petit in front, and will thus have the effect of altering the form of that space, narrowing it from without inwards, and deepening it from before backwards, round the margin of the lens,—a change which may contribute to produce more perfect marginal compression of the lens.

5th. The base of the iris being attached to the ciliary muscle, and the tissue which fixes them both to the ring inside the canal of Schlemm, being of a yielding nature, the outer part of the iris may be carried backwards to some extent by the contraction of the ciliary muscle; while there is nothing in the disposition of the

Dissertation of Van Reeken Disquis. Anat. Microsc. inaug. de Apparat. Oculi Accommod. Utrect, 1855, I am only acquainted through the Dutch extract in the Nederlandsch Lancet for 1855.

parts to prevent the advance of the pupillary margin of the iris, if it should be pressed forwards by another force, such as the bulging of the lens, notwithstanding the contraction of its sphincter muscle. At the same time it is to be remarked, that the contraction of the ciliary muscle may produce tension of the membrane bounding the aqueous chamber in front, as well as that of the vitreous humour.

6th. If we suppose the sphincter muscle to have power sufficient to overcome the radiating fibres, as seems somewhat probable, it is possible that, as Cramer holds, both sets of muscular fibres of the iris may be, during near adjustment, in a state of contraction at the same time, by which a greater degree of tension of the internal muscular apparatus would be produced. But even if this be not admitted, and we suppose the sphincter alone to be in action, it is obvious that the combined effect of the contraction of this part of the iris and of the ciliary muscle will be to produce a marginal compression of the lens, to which the ciliary processes and canal of Petit contribute; and that, while the posterior part of the lens is supported by the tension of the choroid and hyaloid membrane round the vitreous humour and behind the lens, the iris and lens are free to move forwards principally at one part, viz., towards the middle of the anterior surface.

These anatomical facts, together with some physiological observations, appear to furnish the key to the explanation of the mechanism by which the change of form of the lens is effected.

That the change of adjustment from distant to near vision is of a muscular nature can scarcely be doubted. This is, as already remarked, evident from the sensations which accompany the effort. But the fact has received a more direct proof from the experiments of Cramer, from which it appeared, that when the isolated eye of a recently-killed young seal was subjected to the stimulus of a rotating magneto-electric battery, it underwent a change similar to that which occurs in the living eye when its adjustment is altered from distant to near vision. The same result was obtained from experiments on the eyes of pigeons; but these experiments were unsuccessful in the eyes of dogs and rabbits, because probably of the extreme contraction of the pupil, and of the opacity produced by the battery, which in these animals prevented the observation of the variations in the distinctness of an image on the retina, by which the changes of adjustment were ascertained. This experiment on the isolated eye may be held also to prove, that the adjustment depends on the action of a muscular apparatus within the eyeball, and not on that of the external muscles.

Dr. Young having been convinced that the change of adjustment must consist in a change of form of the lens alone, and that no means capable of changing its curvature could be supposed to exist external to the lens itself, adopted the view, in which he subsequently found that he had been long before anticipated by others, that the fibres of the lens are of a muscular kind, and by their own contraction produce the deepening of its curvature. But the more accurate knowledge of the minute anatomy of the textures, and of the lens itself, which has resulted from modern researches, affords no support to this view; and it has been still more decidedly disproved by the direct experiments of Cramer and others, who found that the crystalline lens of recently-killed animals undergoes no change of form whatever, when subjected to the powerful stimulus of a rotating battery. The alteration in the form of the lens must depend, therefore, on the action of the internal muscular apparatus of the eye, which, in man, consists of the iris and ciliary muscle.

With regard to the comparative share which the iris and ciliary muscle take in the act of adjustment, it seems probable that they both are employed in effecting the change; but there are several circumstances which appear to show that the ciliary muscle is of the two the most intimately connected with it, and that the iris is less essential than by many has been supposed.

It is true that Cramer, who holds that the iris is the most important agent of adjustment, appears to have experimental ground for that opinion; for he found that, in the eyes of animals, in which he had previously ascertained changes of adjustment to be produced by galvanic irritation, when the iris was divided, these changes could no longer be induced. But there might be considerable difficulty in the accurate performance of such an experiment; and there are several well-ascertained facts of an opposite kind, which tend rather to prove that the function of the iris is in man subordinate in the act of adjustment.

In the first place, it may be stated that the size of the pupil may undergo considerable variation, according to the amount of light entering the eye, without interfering with the maintenance of a steady adjustment to a near or distant object. E. H. Weber, of Leipzig, has shown, in his last essay on the motion of the iris,* that the motions of the iris are not by any means invariably associated with changes of adjustment. As a remarkable example of their occasional independence, I may refer to the case of Dr. Paxton, described in the last number of this Journal, in which I found that either a near or a distant adjustment, with distinct vision in each case, could be steadily maintained while he alternately contracted and dilated the pupil. It appears from a statement in Funke's edition of Wagner's Physiology, that Hueck possesses a somewhat similar power, and I think it probable that this phenomenon may be more common than is hitherto known.

The effect of belladonna has generally been supposed to be the destruction or impairment of the adjusting power; but I have found, as the result of experiments made upon the eye of a person whose pupil was dilated to a considerable extent with atropine, that although the focal length of the eye was increased by several inches as compared with the other unaffected eye, the power of producing changes of adjustment was as entire in the dilated eye as in the other. It was only necessary, therefore, to compensate for the reduced refracting power of the eye in which the pupil was dilated, by employing an artificial convex lens, to bring it to the same state as the other eye.

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* Summa Doctrina de Motu Iridis, 1851.

Lastly, additional confirmation of this view is given by the remarkable observations recently made by Ruete, already quoted, in which he found, that in several instances, notwithstanding the entire absence of the iris, the power of adjustment remained perfect.

The view that the iris may by itself be the means of producing adjustment for near vision by the mere diminution of the aperture of the pupil, has arisen from the well-known experiment, in which it is found that a small body may be viewed distinctly greatly within the usual distance of distinct vision, by looking at it through a minute aperture, such as a pin-hole in a card. But it is to be remarked, that this apparent shortening of the focus of the eye proceeds merely from the circumstance that the margin of the aperture, less than the pupil, cuts off the more divergent rays, and admits only those which are more nearly parallel; and though the iris may in reality have some effect in this manner, by varying the size of the pupil, yet it appears, as Helmholtz remarks, that, while looking through the minute aperture, a distant object still appears indistinct when a near one is viewed, and a near one appears indistinct when a more distant one is viewed. There is therefore an adjusting power in the eye, independently of the iris; but this part, no doubt, contributes to the adjusting change.

Considerable difficulty has been felt by most persons in understanding the manner in which the compressing action of the internal muscular apparatus may be applied to the lens. Many, indeed, have held that the situation and arrangement of the iris and ciliary muscle in relation to the lens, are incompatible with their exercising any direct compressing force upon that body; and this circumstance, as well as the remarkable vascularity of the choroid membrane and ciliary processes, appear to have suggested the view that the action of the muscles might only be of an indirect kind, and might operate by varying the amount of blood contained in one or other of these highly vascular parts.* But notwithstanding the attractive ingenuity of several of these views, it is to be remarked that the act of adjustment is far too rapid to admit of the supposition that the filling or emptying of blood-vessels under muscular pressure could be the cause of the change of form of the lens. I have found that in most persons, and in one individual especially, upon whom I have very frequently made the catoptric observations, the actual shifting of the anterior lens image during adjustment is instantaneous, even although the effort to produce it appears to the individual himself to occupy an appreciable space of time. I found, farther, that the same individual could regulate by the will whether the act of adjustment, as indicated by the shifting of the image, should be instantaneous or gradual. It is to be remarked also, that those who have held this view are not agreed as to the precise effect on the state of the blood-vessels which the muscular contractions will produce; one, as Fick (*Müller's Archiv*, 1853, p. 449), holding that the pressure on the lens is produced in near adjustment by the emptying of the blood-vessels of the ciliary processes into the vasa vorticosa of the choroid; while another, as Czermak (quoted by Helmholtz), considers that the ciliary processes are most full of blood during the contraction of the ciliary muscle. The use of these very remarkable vascular processes appears to be a problem yet to be solved.

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* This is a view which has been held also by some of those who have believed the act of adjustment to consist in a change of position, rather than of the form of the lens. Among the most ingenious advocates of this view, I may refer to W. Clay Wallace, whose Essay on the Accommodation of the Eye to Distances, republished at New York in 1850, exhibits much learning and judicious observation on this subject.

Professor Forbes advanced the ingenious view (Transactions of the Royal Society of Edinburgh for 1844), that the pressure applied to the lens in adjustment may be of a hydrostatic kind, through the fluids by which it is everywhere surrounded; and, farther, that the increased curvature which he, along with Young, regarded as the essential change in near adjustment, might be determined, under the hydrostatic pressure, by the greater density and deeper curvature of the central part or nucleus of the lens. Professor Forbes took for granted that the compression might be effected by the external muscles of the eyeball—a view which, from what has already been said, it will be seen that most physiologists are now disposed to abandon, but which is not altogether essential to his theory. But he had not himself ascertained by experiment the effect of hydrostatic pressure on the lens. This has since been done by De Haldat (*Comptes rendus*, tom. xx. p. 1561), with a negative result. Although, however, from this it would appear that an equal hydrostatic pressure on every part of the surface of the lens does not cause an increased curvature of that body, the suggestion of hydrostatic pressure still deserves to be kept in view, in connection with the more limited manner in which it may be applied, that is, to the posterior surface and marginal part of the lens, through the fluid of the vitreous humour and the canal of Petit. It is not impossible also that the form of the harder and more spherical nucleus may have some effect in assisting or in guiding the change. But I must remark, that I have not observed such a difference in the form and consistence of the nucleus from that of the external layers of the human lens, as to make it probable that this can have any considerable effect in the eye of man.

Having now taken the circumstances before mentioned into consideration, having carefully observed in sections of the eye, purposely made, the attachments of the iris and ciliary muscle, and the position and relations of the lens and ciliary processes, and having endeavoured to estimate fairly the effect of different forces in altering the form of the lens, I am inclined to give the following explanation of the mechanism by which the change of form of the lens, accompanying focal adjustment, may be effected. In this explanation, I may state, I have followed Cramer, Donders, Helmholtz, and Van Reeken, and have not found myself under the necessity of modifying, in any great degree, the views propounded by these authors.

In adjustment for distant vision, which is usually the state of rest of the eye, the flattened form of the lens is maintained principally by the elasticity of the parts, and more immediately by the tension of the elastic fibres of the zonule of Zinn, or suspensory ligament, which pass to unite with the capsule of the lens, both on the anterior and posterior surface, near its margin.

In adjustment for near vision, which is an active condition, the increased curvature and advance of the anterior surface of the lens, together with the other attendant changes in its form, are effected by the combined action of the ciliary muscle and iris, which compress the marginal part of the lens by their own direct action, and through the ciliary processes and fluid of the canal of Petit.

By the contraction of the ciliary muscle, the attachment of this muscle itself, and of the base of the iris, along the line of junction of the cornea with the sclerotic, is drawn somewhat backwards; and thus the outer part of the anterior aqueous chamber recedes, and is widened transversely. The pupillary margin of the iris, though contracted by its sphincter muscle, is advanced by the bulging of the lens, upon which it lies closely applied.

It may be doubtful whether the radiating fibres of the iris contract actively, or are only in a state of tension between the sphincter and the ciliary muscle; but, in either case, the outer part of the iris will press upon the margin of the lens in front.

The external and longest fibres of the ciliary muscle, whose contraction, as Van Reeken remarks, must be the greatest, proceeding towards the ora serrata, draw forward that part of the choroid membrane, and thus have the effect of relieving the tension of the elastic fibres of the suspensory ligament of the lens.

The remaining part of this muscle, inserted into the exterior of the ciliary processes and suspensory ligament, must gather them together, rendering them shorter from without inwards, and narrowing them from before backwards, so as to support the vitreous humour behind the lens, and thus prevent its moving backwards. The yielding nature of the attachment of the iris and ciliary muscle to the line of junction of the cornea and sclerotic, may allow the ciliary muscle also to act on the membrane of Descemet, so as to give increased tension and support to the fluid in the aqueous chamber.

The combined action of the inner fibres of the ciliary muscle and of the iris, is to carry the ends of the ciliary processes against or near to the margin of the lens, and to produce compression round that margin; the effect of which pressure may be rendered more equal by its action through the fluid of the canal of Petit. This canal is deepened during the action from before backwards, and its fluid may thus convey the pressure to a greater extent of the margin of the lens. At the same time, the direct pressure of the outer part of the iris on the marginal part of the anterior surface of the lens prevents the advance of that body. The lens therefore bulges, especially at its central portion, and it seems even possible that it may bulge to a greater degree through the pupil than elsewhere.*

Had space permitted, I might now have proceeded to treat of several collateral parts of this subject. I will only farther detain the reader, however, with one or two brief remarks.

The close association between movements of inward direction or convergence of the optic axes, and the change of adjustment for near vision, points to the third pair or common oculo-motor nerve as the channel through which this change is influenced by the will or by other causes. It is to be observed, however, that in several well-marked cases of paralysis of this nerve, the power of adjustment has been found unimpaired. This may be accepted as a proof that the change of adjustment is independent of the perfect action of the external muscles of the eyeball; but if adjustment is a voluntary act, and the ciliary motor nerves of the iris and ciliary muscle are derived from the third pair, it is difficult, in our present imperfect state of knowledge of the functions of the ophthalmic ganglion, to understand in what manner the power of these nerves could be preserved in a general paralysis of the whole third pair. We must either suppose that the paralysis was incomplete, or that some remarkable modification in the properties of the nerves has occurred in connection with the ganglionic structure.

The change of the eye to the state of adjustment for distant vision, may, in most instances, be considered as of a passive nature; the sphincter of the iris and the ciliary muscle becoming relaxed, and the elasticity of the suspensory ligament, or other parts, restoring the flattened form of the lens. The dilatation of the pupil which accompanies this change, may be due to the relaxation of the sphincter alone. But it is not uncommon to find persons who possess, in some degree, an active power of dilating the pupil. Dr. Paxton, as already mentioned, possesses this power to an unusual extent; and I have, since my attention was called to the subject by the observation of his case, seen several other instances of considerable dilating power, though in none have I as yet seen the same phenomenon as in Dr. Paxton of the existence of a power of dilatation and contraction of the pupil, while the vision remained distinct for a fixed object.

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* While the above was being printed, I have seen in the first part of the Archiv. für Ophthalmologie for 1857, a paper by H. Müller on the Mechanism of Accommodation, in which he describes the inner part of the ciliary muscle as composed of circular fibres, and ascribes to this part of the muscle a considerable share in the act of compressing the margin of the lens; a view in which, admitting the existence of the circular fibres, I should be disposed to coincide.

In two instances of this kind which I have observed carefully, the individuals while keeping their eyes fixed upon a near object, have thrown it completely out of focus, at the same time dilating the pupil, and have reduced the refracting power considerably below that for distant vision, elongating the focus of the eye by four or five inches; but I found, by the employment of the optometer, that in this reduced state of the eye, as I would call it, the power of varying the adjustment remained to the same extent as with the eye in its natural state. In these instances, which I believe to be more numerous than is commonly known, we perceive a power of reducing the refracting power of the eye, dependent, apparently, chiefly on a dilatation of the pupil, while the adjusting changes can still take place to the usual extent in the reduced condition. This is somewhat similar to what I have previously stated to be the effect of belladonna, and seems to furnish additional evidence of the independence of the action of the iris and the change of adjustment, and in favour of the view that belladonna produces dilatation of the pupil by stimulation, direct or mediate, of the radiating fibres.

This dilatation of the pupil appears generally to be associated with the action of one or both of the external recti muscles; and I found that the individuals possessing the power of dilatation, when keeping it up for a long time, were conscious of effort in the seat of these muscles. It is very rare to find persons who have the power of voluntarily diverging the optic axes beyond parallelism. In one instance of this kind, I am informed by letter from the individual himself, that there is a slight dilatation of the pupil; and Mr. Bell of Edinburgh has stated to me, that he has made a similar observation in two instances of occasional dilatation of the pupil, without apparent paralysis of the third pair, or amaurosis.[*]

[*] I refrain from entering here again on the complicated subject of the nervous influence which may be supposed to regulate the motions of the iris. In connection, however, with some of the remarks in my former paper, I may refer to the interesting histories of cases of ptosis and paralysis of the third pair of

In connection with this subject, I would also remark that it seems desirable to obtain from oculists, or those having a large experience of suitable cases, a greater number of observations in regard to the state of the adjusting power in persons, from whose eyes the crystalline lens has been extracted. It is the common belief among oculists, as the result of observation, that the power of adjustment is entirely lost after extraction of the lens; and Dr. Young instituted very careful experiments with the optometer in several such persons, which appeared fully to bear out the general belief, in which we should also feel inclined to place still more confidence from the recent discoveries, described in the foregoing pages, as to the actual change in the lens which accompanies adjustment. I must mention here, however, notwithstanding its apparent inconsistency with these views, a remarkable case in which, although the lens had been extracted many years before, I have found the power of adjustment to be as perfect as in most other persons. In this case I have ascertained by catoptric examination, that neither of the reflections of a light from the lens, such as are seen in the natural eye, are present; and I did not perceive any shifting of the corneal image during adjustment, so that I am at present quite at a loss to conjecture by what substitute for the usual mechanism adjustment is effected in this individual. The subject requires a fuller investigation than I have the opportunity of making at present.

In conclusion, I have farther to state that I have, in the foregoing paper, confined my remarks entirely to the process of adjustment as illustrated by observations in the human eye. But it does not necessarily follow, from the facts recorded in these pages, that, in all animals, the change of form of the lens is the only means by which focal adjustment is effected. Without doubt an elongation of the axis of a spherical lens, by bringing it into an ellipsoidal figure, might deepen its curvature, and be the means of adjustment for near vision; but it is also possible that in some animals an advance of the lens to a greater distance from the retina may contribute to the same result; for the ciliary muscle appears to be capable, in certain circumstances, of moving the lens forward as well as of altering its form. I forbear, however, from entering farther at present on the discussion of these topics.

DESCRIPTION OF THE PLATE.

Fig. 1. Two enlarged views of the appearance of the reflected images from the flame of a candle, as seen in the catoptric observation of the eye: D, in adjustment for distant; N, in that for near vision; *c*, the reflection from the cornea; *a*, that from the anterior surface of the lens; *p* that from the posterior surface.

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nerves by Mr. John F. France, in various volumes of Guy's Hospital Reports from 1846 to 1856, with some suggestive remarks on this subject.

Fig. 2. Two enlarged views, on a somewhat smaller scale than those in fig. 1., of the position of the reflections of a double light from the different surfaces of the eye (after Helmholtz). The letters refer to the same parts as in the foregoing figure.

Fig. 3. Diagrammatic figure, after one suggested by Donders, to explain the change of place of the anterior lens image in the preceding figures: L, L′, the lens in its two states of flat and bulging on its anterior surface, represented on a proportionally large scale; C, the cornea; I, the light; E, the position of the eye of the observer; *c*, the corneal image; *a*, the anterior lens image for distant vision; *a′*, that for near vision; *p*, the posterior image.

Fig. 4. Sectional diagram, modified from one given by Helmholtz, of the anterior part of the eye; the lens and other parts being represented on the right side as in adjustment for near vision; on the left side, as for distant vision: *c*, the cornea; *i*, iris; *s*, sclerotic; *ch*, choroid membrane; *r*, retina; *h*, hyaloid membrane; *cm*, ciliary muscle; *cp*, ciliary processes; *o*, canal of Petit and suspensory ligament of the lens; *l*, the flat lens; *l′*, the lens altered in form for near vision.

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